3.2 Fuel Systems

3.2.1 Introduction

NOTE:

This chapter applies to new and substantially improved structures that must be built in compliance with the minimum requirements of the NFIP. Many of the structures that were built prior to the adoption of floodplain management regulations by communities have building utility systems that are not resistant to flood damages. For additional information on how to protect building utility systems in these structures, see Chapter 4 on Existing Buildings.

The components of the fuel systems in residential and non-residential structures can be organized into two categories:

1. Fuel storage tanks
2. Fuel lines, meters, and control panels

There are four major concerns when considering the protection of fuel system components. They are:

- Buoyancy
- Impact Loads
- Scour of lines
- Movement of Connection

The tank shown in *Figure 3.2.1* is shown outside of the building. This type of installation is not the typical installation for all applications. Some tanks may be located inside a structure to provide additional protection from damage during flooding.

In general, the figures in this chapter attempt to illustrate some general practices that meet the requirements of the National Flood Insurance Program (NFIP). Local codes permit many variations that also meet NFIP regulations. Please refer to your local code officials for specific practices that may meet both NFIP regulations and local code.

3.2.2 NFIP Requirements

The NFIP requires that the fuel system for a new or substantially improved structure located in a Special Flood Hazard Area (SFHA) be designed so that floodwaters cannot infiltrate or accumulate within any component of the system. See *Table 3.2.2* for a summary of compliant mitigation methods.

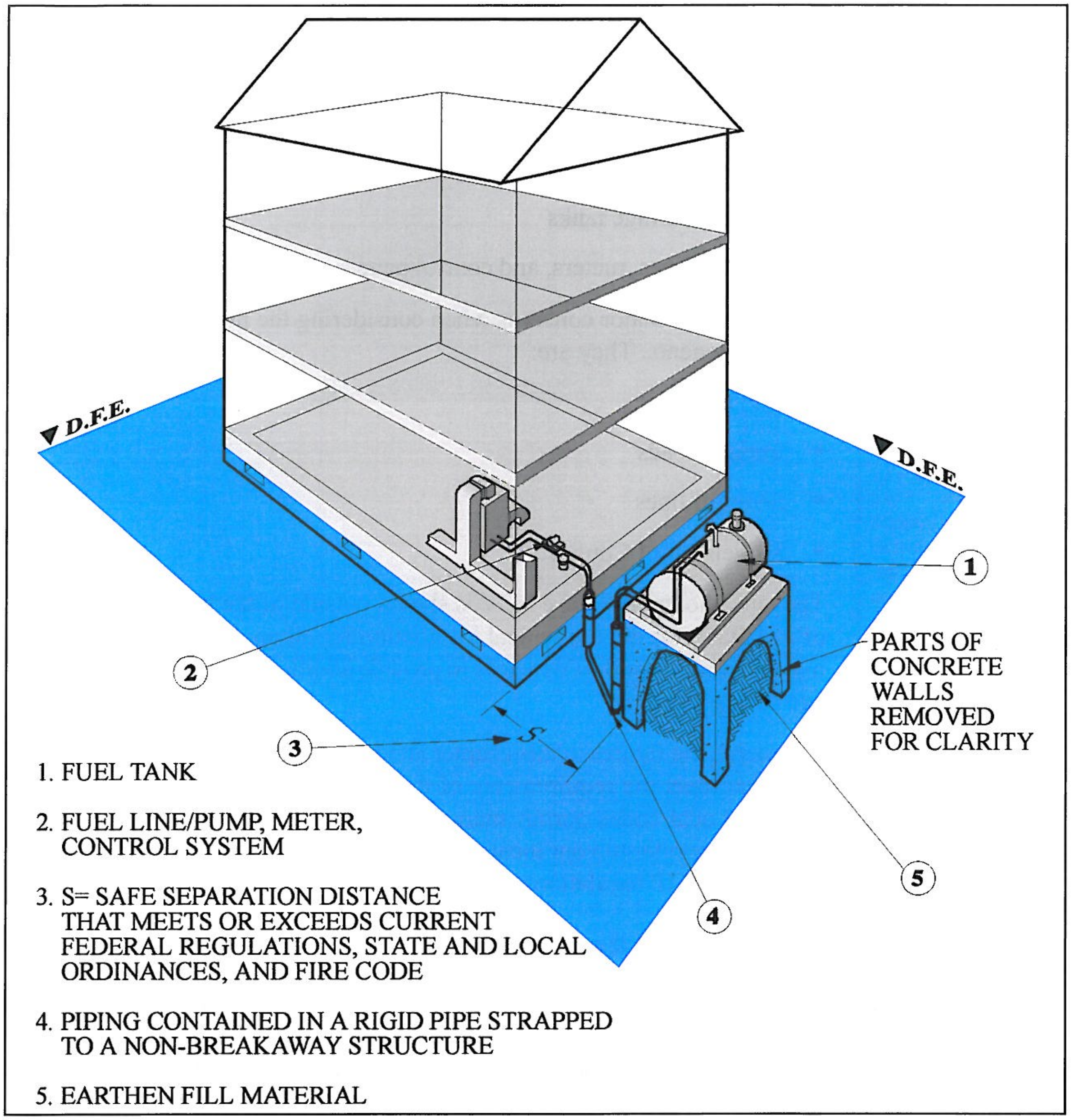

Figure 3.2.1: An outline of a fuel system with the fuel tank elevated on a platform beside a house on a crawl space in a flood-prone area

Methods of Mitigation	A Zones	V Zones
1. Elevation	Highly Recommended	Minimum Requirement
2. Component Protection	Minimum Requirement	Not Allowed*

Table 3.2.2: Summary of NFIP regulations
***Allowed only for those items required to descend below the DFE for service connections.**

NOTE:
The Design Flood Elevation (DFE) is a regulatory flood elevation adopted by a community that is the BFE, at a minimum, and may include freeboard, as adopted by the community.

1. **Elevation** refers to the location of a component above the Design Flood Elevation (DFE).

2. **Component Protection** refers to the implementation of design techniques that protect a component or group of components located below the DFE from flood damage by preventing floodwater from entering or accumulating within the system components.

3.2.3 Fuel Storage Tanks

NOTE:
Refer to manufacturers' literature and professional tank installers for information regarding the proper installation of fuel storage tanks.

Where a structure is not connected to public gas service, the fuel for a non-electric Heating, Ventilating, and Air Conditioning (HVAC) system and other non-electric equipment is stored on-site in tanks either underground or above ground and inside or outside the building. Most modern commercial fuel tanks are of double-walled construction while most residential fuel tanks are of single-walled construction. The type of construction of the tank should be determined as some of the techniques may not apply to some types of tanks.

Both underground and above ground fuel storage tanks are vulnerable to damage by floodwaters, as illustrated by the following:

- An underground tank surrounded by floodwaters or saturated soil will be subjected to buoyancy forces that could push the tank upward. Such movement of a tank may cause a rupture and/or separation of the connecting pipes.
- Above ground tanks in V Zones and A Zones that experience velocity flow are not only subject to buoyancy forces, but they are also exposed to lateral forces caused by velocity flow, wave action, and debris impact.

- An underground tank in a V Zone can be uncovered and exposed by erosion and scour, making it even more vulnerable to buoyancy forces, velocity flows, wave action, and debris impact.

Buoyancy is described in detail later in this section. The effects of buoyancy and/or those of velocity flow can move a tank from its location, break it open, and cause fuel leakage into floodwaters. Such leakage creates the risk of fire, explosion, water supply contamination, and possible health and environmental hazards which would delay cleanup and repair work necessary to occupy the building.

Elevation

The most effective technique for providing flood protection for a fuel storage tank is elevation of the tank on a platform above the DFE. *Figure 3.2.3A* shows a tank on an elevated platform. The depth of the footing will be dependent upon the hazards at the site. The following outlines some additional considerations when protecting fuel systems:

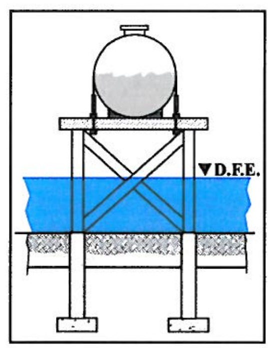

Figure 3.2.3A: A fuel tank elevated above the DFE on a platform in a velocity flow area

- The tank should be anchored to the platform with straps, which would constrain the tank in wind, earthquake, and other applicable forces.
- In coastal zones, the straps should be made of non-corrosive material to prevent rusting.
- In velocity flow areas, the platform should be supported by posts or columns that are adequately designed for all loads including flood and wind loads.
- The posts or columns should have deep concrete footings embedded below expected erosion and scour lines.
- The piles, posts, or columns should be cross-braced to withstand the forces of velocity flow, wave action, wind, and earthquakes; cross-bracing should be parallel to the direction of flow to allow for free flow of debris.
- In non-velocity flow floodplains, elevation can also be achieved by using compacted fill to raise the level of the ground above the DFE and by strapping the tank onto a concrete slab at the top of the raised ground. *Figure 3.2.3B* shows a tank located atop fill.

CAUTION:

Fill is not suitable for use in areas subject to erosion and scour unless fill has been armoured.

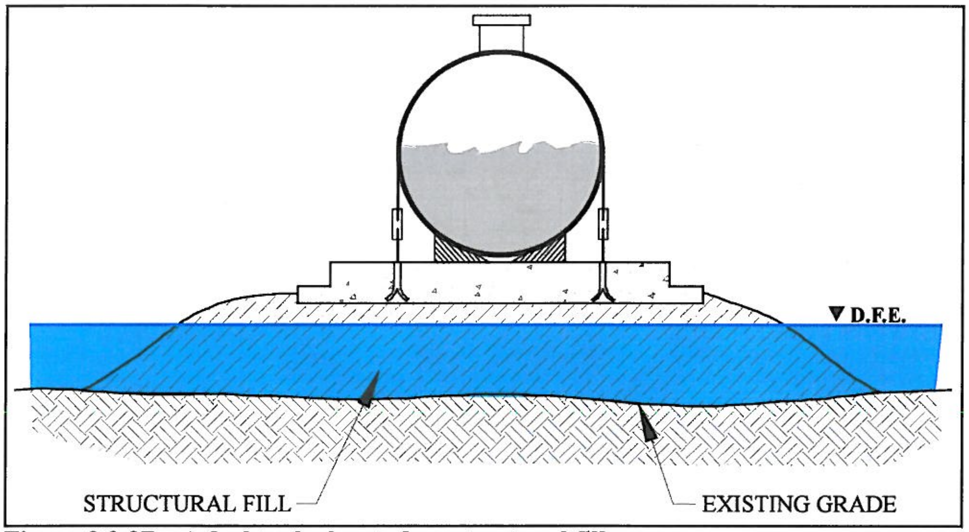

Figure 3.2.3B: A fuel tank elevated on structural fill

Component Protection

If a fuel tank must be located below the DFE in an SFHA, it must be protected against the forces of buoyancy, velocity flow, and debris impact. This can be achieved by the following methods:

A. Anchoring Tanks Below Ground

1. A fuel tank located below ground in a flood-prone area can be anchored to a counterweight in order to counteract the buoyancy force that is exerted by saturated soil during a flood.

   One effective method is to anchor the fuel tank to a concrete slab with (non-corrosive) hold-down straps, as shown in *Figure 3.2.3C.* The straps must also be engineered to bear the tensile stress applied by the buoyancy force. The maximum buoyancy force is equal to the weight of floodwaters which would be required to fill the tank minus the weight of the tank (see Section 3.2.3.1).

2. An alternative design technique involves strapping the tank to concrete counterweights on opposite sides of the tank, as shown in *Figure 3.2.3D.* The use of this technique is ideal for existing tanks servicing substantially improved structures. Note that the tank in this example is sitting in the concrete anchor, not on it.

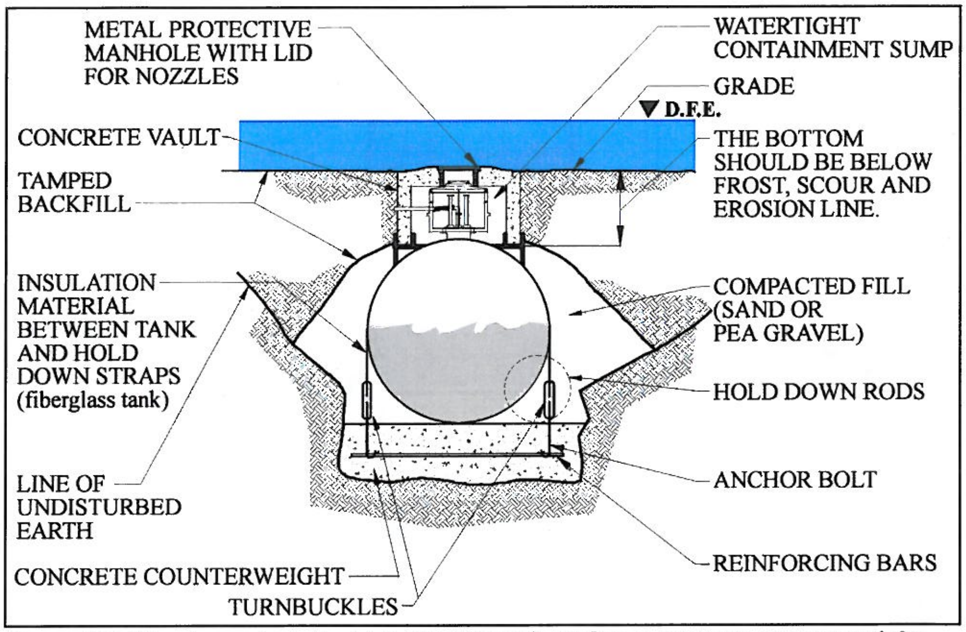

Figure 3.2.3C: An underground fuel tank anchored to a concrete counterweight
Courtesy of Adamson Global Technology Corp.

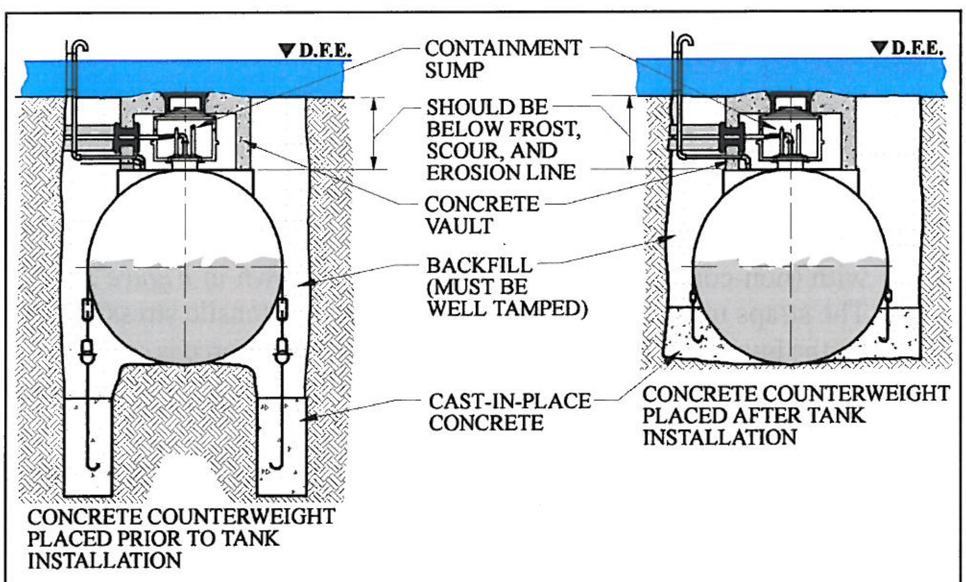

Figure 3.2.3D: An underground fuel tank anchored onto poured-in-place concrete counterweights

CAUTION:

Underground Storage Tank (UST) use should be minimized due to environmental concerns.

NOTE:

Soil conditions can dramatically effect buoyancy forces. Always consult with a geotechnical engineer or other knowledgeable professional that is familiar with the local soil conditions when designing anchors to counter buoyancy forces.

NOTE:

Always refer to local code officials to determine the proper location for tanks. For example, codes typically specify that propane tanks be strapped down at least ten feet from any wall or ignition source.

3. Another technique for countering the buoyancy force is by anchoring the tank using earth augers. The holding strength of an auger is a function of its diameter and the type of soil into which the auger is embedded. The use of straps attached to augers is often well suited to an existing tank that services a substantially improved structure. In order to use this system without the risk of failure, proper soil conditions must exist. Always refer to a geotechnical engineer or other knowledgeable professional when designing auger anchors to combat buoyancy forces (see Section 3.2.3.1). Please refer to the tank manufacturers' literature to determine the proper configuration for the straps.

B. Anchoring Tanks Above Ground

A fuel tank located above ground but below the DFE must be secured against flotation and lateral movement. This requirement applies as well to portable fuel tanks such as propane tanks.

In A Zones, that are not subject to velocity flows, the following techniques can be used:

Mounting and strapping a tank onto a concrete slab or strapping a tank onto concrete counterweights on both sides of the tank. The anchoring straps are typically connected to anchor bolts by turnbuckles that are installed when the concrete is poured. Please refer to the supplier's data when selecting the strap locations for anchoring tanks because a tank can rupture when buoyancy forces are too great. See *Figure 3.2.3E* for an example of a typical compliant strap configuration. In most applications, brackets, like those shown in *Figure 3.2.3F,* are designed to withstand the weight of the tank only. Buoyancy forces can exceed the weight of the tank and cause the brackets to fail. A structural engineer or manufacturer's literature should be used to verify that the bracket used to hold the tank can withstand buoyancy forces (see Section 3.2.3.1).

In coastal areas the strapping mechanism for securing a fuel tank onto a concrete slab must be made of non-corrosive material. The total weight of the counterweights or the concrete slab must be enough to counteract the buoyancy force expected to be exerted on the tank surrounded by floodwater (see Section 3.2.3.1). The sizing process for concrete counterweight is discussed in detail in Section 3.2.3.1. The counterweight can be located at or below grade.

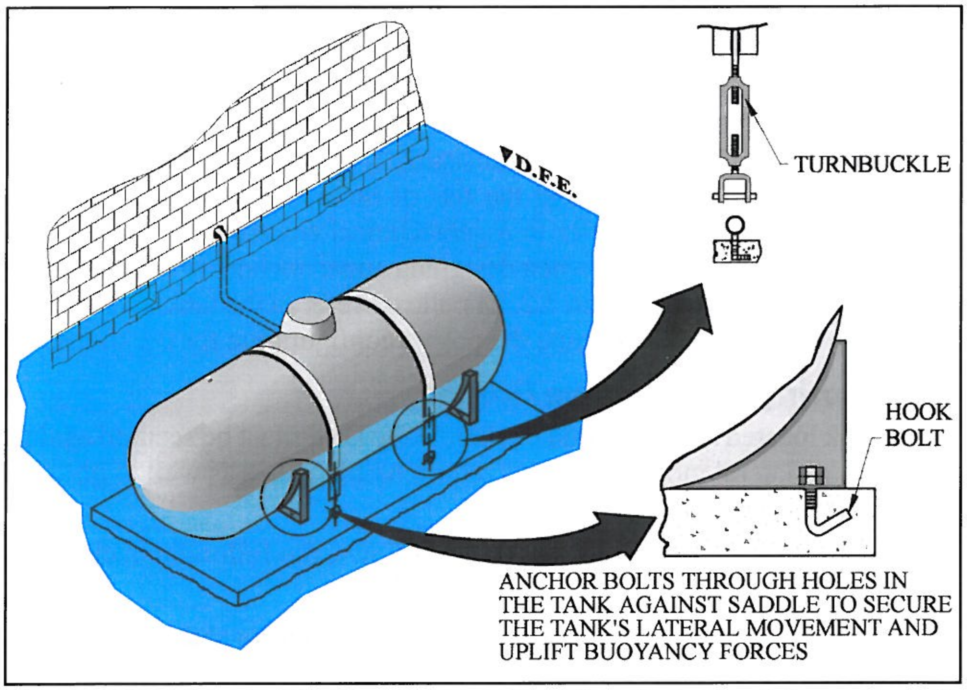

Figure 3.2.3E: A typical tie down strap configuration of a horizontal propane tank

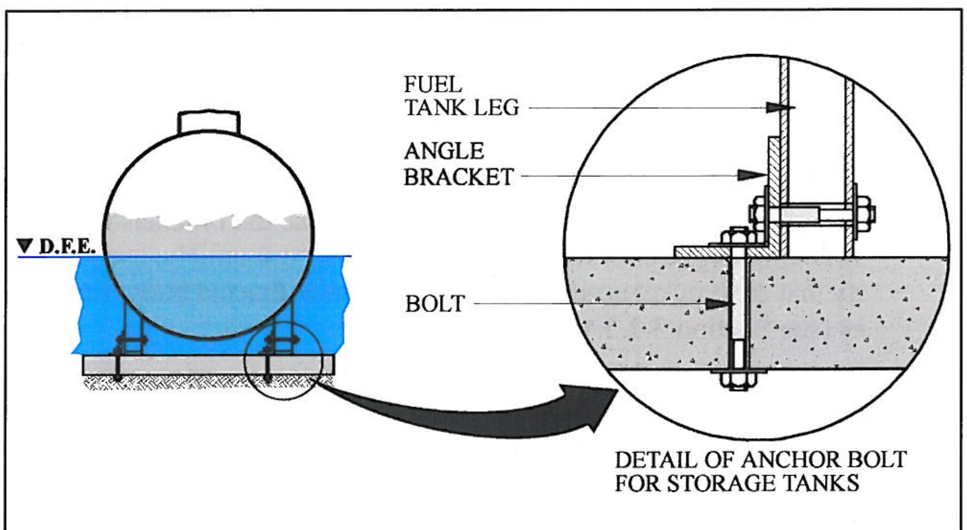

Figure 3.2.3F: A typical tie down configuration of a horizontal propane tank using brackets

NOTE:
Always consult a geotechnical engineer or other knowledgeable professional familiar with local soil conditions when selecting augers.

Strapping a tank to earth augers. The augers and strapping mechanism must be strong enough to withstand the buoyancy force expected during inundation and the lateral forces expected with wind and water. Earth augers are readily available from many manufacturers.

It is important to note that the performance of an auger depends upon the type of soil into which it is embedded. For example, an auger has a greater holding strength in clay soil than in sandy soil. Therefore, if the soil conditions are unknown or if the anchors selected cannot withstand anticipated loads, larger-sized or additional anchors should be used. Generally, the total holding strength of an anchoring system can be increased by increasing the number of augers, the size of the augers, or both. Earth augers and anchoring components are readily available from many manufacturers.

CAUTION:
Above ground tanks under a V-zone building are obstructions and are not permitted.

Because of environmental concerns, underground storage tanks are not recommended. Elevated storage tanks are also problematic because of concerns about impact damage during flooding. Therefore, for elevated tanks, additional protection must be applied against debris impact and the forces of velocity flow. The following technique can be used to prevent damage from debris impact and the forces of velocity flow:

- Protective walls can be constructed around the tank to protect it from debris impact and the forces of velocity flow. The walls must be higher than the DFE, but they do not have to be watertight. Furthermore, there must be drainage holes at the base of the walls for rain water to drain.
- Concrete guard posts can be constructed around the tank to protect it from debris impact.

NOTE:
Though vault tanks are discussed in this manual, their use is typically restricted, due to construction costs, to military and larger commercial applications. However, some residential applications do exist.

C. Vault Tanks

A vault tank is made of a primary steel tank within a secondary steel containment tank. The primary tank is coated with a layer of light-weight concrete. The typical vault is shaped like a rectangle with a sloped top to prevent accumulation of rain water. Vault tanks are available commercially for residential as well as non-residential use.

The vault is anchored to the concrete slab upon which it sits using anchoring beams welded to the bottom of the secondary/outer tank and bolted into the concrete slab. If properly designed and constructed, the anchoring system eliminates the possibility of flotation due to buoyancy, and lateral movement due to wind and seismic activity.

For additional protection against debris impact, the vault may be surrounded by guard posts.

The fuel piping below the DFE must be strapped to the vault or contained in a protective shaft on the landward or downstream side. The vent pipe from the tank must extend above the DFE.

The vault tanks normally come with the manufacturer's calculations of the concrete volume required to counteract for buoyancy.

3.2.3.1 Calculation of Buoyancy Forces

This section addresses the powerful buoyancy forces that are exerted on buried tanks. *Figure 3.2.3.1A* shows the power of buoyancy forces to lift tanks. The tank in the photo is an abandoned gas tank that came up through the asphalt and soil that had covered it. The following formulas and tables are the basic tools used when calculating buoyancy forces acting on tanks.

NOTE: To minimize buoyancy forces, fuel tanks should be re-fueled prior to flooding.

$$F_b = 0.134 V_t \gamma FS$$

Where:	F_b	is the buoyancy force exerted on the tank, in pounds.
	V_t	is the volume of the tank in gallons.
	0.134	is a factor to convert gallons to cubic feet.
	γ	is the specific weight of flood water surrounding the tank (generally 62.4 lb/ft^3 for fresh water and 64.1 lb/ft^3 for salt water.)
	FS	is a factor of safety to be applied to the computation, typically 1.3 for tanks.

Formula 3.2.3.1A: Calculation of buoyancy force exerted on a tank (tank buoyancy)

Net Buoyancy = Tank Buoyancy (F_b) - Tank Weight - Equivalent flood weight of soil (see Table 3.2.3.1A) acting as a counterweight(s) over Tank

Formula 3.2.3.1B: Calculation of net buoyancy force

Soil Type*	Column A S, Equivalent Fluid Weight of Moist Soil (pounds per cubic foot)	Column B Equivalent Fluid Weight of Submerged Soil and Water (pounds per cubic foot)
Clean sand and gravel: GW, GP, SW, SP	30	75
Dirty sand and gravel of restricted permeability: GM, GM-GP, SM, SM-SP	35	77
Stiff residual silts and clays, silty file sands, clayey sands and gravels: CL, ML, CH, MH, SM, SC, GC	45	82
Very soft to soft clay, silty clay, organic silt and clay: CL, ML, OL, CH, MH, OH	100	106
Medium to stiff clay deposited in chunks and protected from infiltration: CL, CH	120	142

Table 3.2.3.1A: Effective Equivalent Fluid Weight of Soil(s)

Soil Type	Group Symbol	Description
Gravels	GW GP GM GC	Well-graded gravels and gravel mixtures Poorly graded gravel-sand-silt mixtures Silty gravels, gravel-sand-clay mixtures Clayey gravels, gravel-sand-clay mixtures
Sands	SW SP SM SC	Well-graded sands and gravelly sands Poorly graded sands and gravelly sands Silty sands, poorly graded sand-silt mixtures Clayey sands, poorly graded sand-clay mixtures
Fine grain silt and clays	ML CL OL MH CH OH	Inorganic silts and clayey silts Inorganic clays of low to medium plasticity Organic silts and organic silty clays of low plasticity Inorganic silts, micaceous or fine sands or silts, elastic silts Inorganic clays of high plasticity, fine clays Organic clays of medium to high plasticity

Table 3.2.3.1B: Soil Type Definitions Based on USDA Unified Soil Classification

$$\text{No. of Hold Down Straps Required} = \frac{\text{Net Buoyancy}}{\text{Allowable Working Load of each strap}}$$

Formula 3.2.3.1C: Calculation of the number of hold down straps

$$V_c = \left[\frac{\text{Net Buoyancy}}{\text{Density of Concrete}} \right] FS$$

Formula 3.2.3.1D: Calculation of the volume of concrete necessary to resist buoyancy

A buoyancy flow chart, *Figure 3.2.3.1B*, and *Example 3.2.3.1* follow *Figure 3.2.3.1A*.

Figure 3.2.3.1A: Tank lifted by buoyancy forces

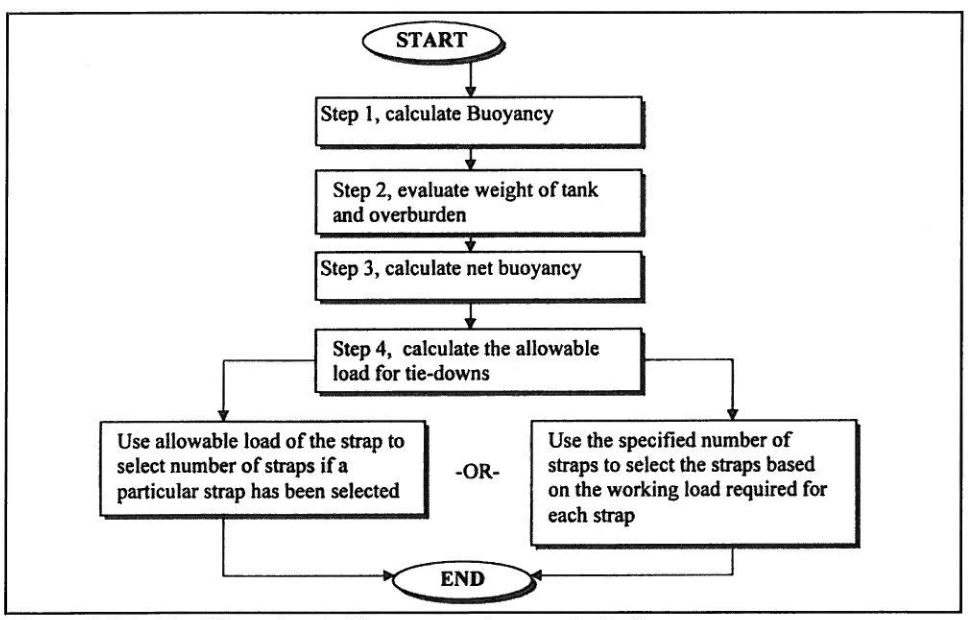

Figure 3.2.3.1B: Flow chart of buoyancy force calculations

Example 3.2.3.1: Calculation of allowable load for tank straps

A 500-gallon fuel tank is going to be located next to a new building in a Zone AE floodplain in silty clay. The site will not be subject to velocity flow, so lateral forces and scour are not major concerns. The client is concerned about the buoyancy forces that will be acting on the tank during a flood. The tank manufacturer specified 3 locations where a strap should be installed to properly spread the load across the tank. A large concrete slab will be installed 6 feet below ground on which the tank will be fastened. The slab will be approximately 1.5 feet thick, and the top will have dimensions of 4 feet by 5.5 feet. What is the allowable load that the tie down straps will be required to withstand?

First, the dimensions of the tank must be determined. This can be obtained from the manufacturer's literature. The double-walled cylindrical tank that the client wants to use is approximately 4 feet in diameter, 5½ feet long, and weighs 650 lb.

Step 1: Using *Formula 3.2.3.1A*, the **Buoyancy Force (F_b)** that will be exerted on the tank, will be calculated:

F_b = 0.134 * 500 * 62.4 * 1.3 = **5,435 lb.**

V_t = 500 gallons

γ = 62.4 lb./ft.^{3} (fresh water)

FS = 1.3 (This value should be verified with a geotechnical engineer familiar with local soil conditions)

Step 2: To determine the equivalent fluid weight of the earth over the tank and counterweight, a geotechnical engineer or other knowledgeable professional should be consulted. In general the following method is used to determine the weight of the soil:

Volume of soil(ft.^{3}) = Tank area (as viewed from top)(ft.^{2}) * Depth of tank(ft.)

Tank area = 4 * 5.5 = 22 ft.^{2}

Depth of soil over tank = 6 – 4 (tank diam.[ft.]) – 1.5 (slab thickness[ft.]) = 0.5 ft.

Volume of soil over tank = $22 * 0.5 + \left[(22*2) - \left(\frac{3.14*2^2*5.5}{2}\right)\right] = 20.5$ ft.^{3}

Density of saturated soil = 106 lb./ft.^{3} (see Table 3.2.3.1A)

Weight of Earth over Tank = 20.5 * 106 = 2,173 lb.

Step 3: Next, **Net Buoyancy Force** should be calculated using *Formula 3.2.3.1B.*

Net Buoyancy = 5,435 - 650 - 2,173 = **2,612 lb.**

Step 4: After the net buoyancy force has been determined, *Formula 3.2.3.1C* can be used to determine either the number of straps or the required **Allowable Load** of each strap. In this example, the manufacturer determined the number and location of straps, so the allowable load will be determined.

Allowable Load(lb.) = Net Buoyancy(lb.)/No. of Hold Down Straps Required.

2,612 / 3 = **871 lb./strap**

Based on these calculations, the three straps should each be selected so that they have an allowable load of 871 pounds.

These calculations have all been based on the assumption that the concrete slab is heavy enough not to be lifted by the tank and straps. As a check, the weight of the tank and the equivalent fluid weight of any additional overbearing soil should be compared to the net buoyancy force to ensure that the buoyant tank will not lift the slab.

Weight of the slab(lb.) + equivalent
fluid weight of overbearing soil(lb.) > **Net Buoyancy Force(lb.)**

The weight of the counterweight slab is calculated using *Formula 3.2.1D.*

Volume of slab(ft.^{3}) = Slab area (as viewed from top)(ft.^{2}) * Thickness of slab(ft.)

Slab area = 4 * 5.5 = 22 ft.^{2}

Thickness of slab = 1.5 ft.

Volume of slab = 22 * 1.5 = 33 ft^3

Density of concrete = 150 lb./ft.^{3} (this must be verified by the local concrete supplier, aggregate densities can very widely depending on source of the material)

Weight of concrete slab = 33 * 150 = 4,950 lb.

As a check, compare the weight of the slab to the net buoyancy force, including a factor of safety.

4,950 lb. > (2,612 * 1.3) = 3,396 lb. ✓

Therefore, the slab weighs enough to prevent the buoyant tank from lifting.